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Remarks

If it is deemed helpful or beneficial to the efficient prosecution of the present application, the Examiner is invited to contact Applicant's undersigned representative by telephone.

Respectfully submitted,



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**SILICON PROCESSING
FOR
THE VLSI ERA**

**VOLUME 1:
PROCESS TECHNOLOGY
Second Edition**

**STANLEY WOLF Ph.D.
RICHARD N. TAUBER Ph.D.**

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xviii

CONTENTS

11.2.4 Obstructed Glow Discharges & Dark-Space Shielding	
11.3 THE PHYSICS OF SPUTTERING,	443
11.3.1 The Billiard Ball Model of Sputtering	
11.3.2 Sputter Yield	
11.3.3 Selection Criteria for Process Conditions and Sputter Gas	
11.3.4 Secondary Electron Production for Sustaining the Discharge	
11.3.5 Sputter Deposited Film Growth	
11.3.6 Species that Strike the Wafer During Film Deposition	
11.4 RADIO-FREQUENCY (RF) GLOW DISCHARGES,	450
11.5 MAGNETRON SPUTTERING,	456
11.5.1 Magnetron Sputter Sources for ULSI	
11.5.1.1 Evolution of Planar Circular Sputtering Sources	
11.5.1.2 Deposition Rate and Thickness Uniformity with Circular Planar Magnetrons:	
11.6 VLSI AND ULSI SPUTTER DEPOSITION EQUIPMENT,	461
11.6.1 The Components of a Generic Sputtering System	
11.6.1.1 Sputtering Targets	
11.6.1.2 Vacuum Pumps for Sputtering Systems	
11.6.1.3 Power Supplies for Sputtering Systems	
11.6.1.4 The Gas Supply for Sputtering Systems	
11.6.2 Commercial Sputtering Systems for 125-mm and 150-mm Wafers	
11.6.3 Commercial Sputtering Systems for 200-mm Wafers	
11.7 PROCESS CONSIDERATIONS IN SPUTTER DEPOSITION,	468
11.7.1 Sputter Deposition of Alloy Films	
11.7.2 The Effects on the Sputter Process of the Transport of the Vaporized Atoms Between the Target and the Substrate	
11.7.3 Wafer Heating During Sputter Deposition	
11.7.4 Faceting and Trenching	
11.7.5 Particle Generation in Sputtering Processes	
11.7.6 Reactive Sputtering	
11.8 STEP COVERAGE & VIA/CONTACT HOLE FILLING BY SPUTTERING,	475
11.8.1 Sputter Deposition of Barrier Layer Films into Contact Holes and Vias	
11.8.1.1 Sputter Deposition with Collimators	
11.8.1.2 Long-Throw Collimated sputtering	
11.8.1.3 Ionized Magnetron Sputter Deposition	
11.9 FUTURE TRENDS IN SPUTTER DEPOSITION PROCESSES,	483
11.10 METAL FILM THICKNESS MEASUREMENT,	483
REFERENCES,	485
PROBLEMS,	487
12. LITHOGRAPHY I: OPTICAL PHOTORESIST and PROCESS TECHNOLOGY	488
12.1 BASIC PHOTORESIST TERMINOLOGY,	488
12.2 PHOTORESIST MATERIAL PARAMETERS,	490
12.2.1 Resolution	

CONTENTS

xix

12.2.1.1 Resolution - Contrast	
12.2.1.2 Resolution - Swelling, Proximity Effects, and Resist Thickness	
12.2.2 Sensitivity	
12.2.3 Etch Resistance and Thermal Stability	
12.2.4 Adhesion	
12.2.5 Solids Content and Viscosity	
12.2.6 Particulates and Metals Content	
12.2.7 Flash Point and TLV Rating	
12.2.8 Process Latitude and Consistency	
12.2.9 Shelf-Life	
12.3 OPTICAL PHOTORESIST MATERIAL TYPES, 500	
12.3.1 Positive Optical Photoresists	
12.3.2 Negative Optical Photoresists	
12.3.3 Chemically-Amplified Deep-UV Resists	
12.3.4 Multilayer Resist Processes	
12.3.4.1 Si-CARL Process	
12.3.5 Contrast Enhancement Layers	
12.3.6 Silylation-Based Processes for Surface Imaging	
12.3.6.1 DESIRE	
12.3.6.2 PRIME	
12.3.7 The Predicted Role of Multilayer and Surface Imaging Technologies	
12.4 PHOTORESIST PROCESSING, 510	
12.4.1 Resist Processing: Dehydration Baking and Priming	
12.4.2 Resist Processing: Spin Coating	
12.4.3 Resist Processing: Soft-Bake	
12.4.4 Resist Processing: Exposure	
12.4.4.1 Standing Waves	
12.4.4.2 Linewidth Variation as Resist Crosses Steps	
12.4.4.3 Swing Curves and CD Variation with Resist Thickness	
12.4.4.4 Reflective Notching	
12.4.4.4 Dyed Photoresists	
12.4.4.6 Anti-Reflective Coatings (ARCs)	
12.4.4.7 Bottom Anti-Reflective Coatings (BARCs)	
12.4.4.8 Top Anti-Reflective Coatings (TARs)	
12.4.5 Resist Processing: Post-Exposure Bake	
12.4.6 Resist Processing: Development	
12.4.7 Resist Processing: After-Develop Inspection	
12.4.7.1 Linewidth Variation and Control	
12.4.7.2 Linewidth Measurements	
12.4.8 Resist Processing: Post-Development-Bake	
12.4.9 Resist Processing: Photostabilization of Resists	
12.5 PHOTORESIST PROCESSING SYSTEMS, 538	
REFERENCES, 541	
PROBLEMS, 544	

xx

CONTENTS

13. LITHOGRAPHY II: OPTICAL ALIGNERS and PHOTOMASKS

545

- 13.1 THE HISTORY (AND FUTURE) OF MICROLITHOGRAPHY, 546
- 13.2 BASICS OF OPTICAL SCIENCE FOR MICROLITHOGRAPHY, 548
 - 13.2.1 Basic Terminology of Plane Waves of Light
 - 13.2.2 Diffraction, Numerical Aperture, and Resolution
 - 13.2.2.1 Resolution of the Optical System
 - 13.2.2.2 Resolution - The Rayleigh Criterion
 - 13.2.2.3 Resolution - The Optical Grating
 - 13.2.2.4 Resolution - Fourier Optics Perspective
 - 13.2.2.5 Coherence in Optical Systems
 - 13.2.2.6 Resolution - Modulation Transfer Function
 - 13.2.2.7 Resolution - Impact of the Depth of Focus:
 - 13.2.2.8 A General Resolution Criterion - The Focus-Exposure Process Window:
 - 13.2.3 Resolution Enhancement Techniques Involving the Stepper Optical System
 - 13.2.3.1 Off-Axis Illumination:
 - 13.2.3.2 Multiple Exposures Through Focus (FLEX)
- 13.3 PATTERN REGISTRATION, 582
 - 13.3.1 Definition of Alignment and Overlay
 - 13.3.2 Interfield and Intrafield Overlay Errors
 - 13.3.3 Interfield Errors
 - 13.3.4 Intrafield Errors
 - 13.3.5 Overlay Metrology
- 13.4 OPTICAL LITHOGRAPHY EXPOSURE SYSTEMS, 588
 - 13.4.1 Light Sources and Illumination Systems for Optical Lithography
 - 13.4.1.1 Mercury Arc Lamps
 - 13.4.1.2 The Arc-Lamp Illumination System
 - 13.4.1.3 Excimer Laser DUV light Sources
- 13.5 OPTICAL PROJECTION SYSTEMS, 595
 - 13.5.1 1:1 Scanning Projection Aligners
 - 13.5.2 Reduction Step-and-Repeat Projection Aligners (Reduction Steppers)
 - 13.5.3 Non-Reduction Step-and-Repeat Projection Aligners (1X Steppers)
 - 13.5.4 Step-and-Scan Projection Systems
 - 13.5.5 Stepper Wafer Handling System
 - 13.5.6 Temperature, Vibration, and Environmental Control of Steppers
- 13.6 ALIGNMENT SYSTEMS IN STEPPERS, 605
 - 13.6.1 Off-Axis Alignment Systems
 - 13.6.2 Through-the-Lens Alignment Systems
 - 13.6.3 Alignment Marks and Their Detection
 - 13.6.4 Alignment Strategies
- 13.7 MECHANICAL ASPECTS OF STEPPER WAFER STAGES, 610
 - 13.7.1 Wafer Stage Positioning and Wafer Chuck Design
 - 13.7.2 Automatic Focussing Systems in Steppers
 - 13.7.3 Automatic Leveling Systems

CONTENTS

xxi

13.8 MASK AND RETICLE FABRICATION,	615
13.8.1 Terminology and History of Photomasks	
13.8.2 Fabrication of Photomasks and Reticles	
13.8.2.1 Glass Quality and Preparation	
13.8.2.2 Glass Coating (Chrome)	
13.8.2.3 Mask Imaging (Resist Application and Processing)	
13.8.2.4 Pattern Generation	
13.8.3 Mask and Reticle Defects and Their Detection and Repair	
13.8.3.1 Repairing Defects in Masks and Reticles	
13.8.4 Pellicles	
13.8.4.1 Inspecting Masks and Reticles with Pellicles Attached	
13.8.5 Critical Dimension and Registration Inspection of Masks and Reticles	
13.8.6 Storage, Transport, and Loading of Reticles into the Stepper	
13.8.7 Optical Proximity Correction (OPC)	
13.8.8 Phase Shift Masks (PSM)	
13.9 MICROLITHOGRAPHY TRENDS,	635
13.9.1 The Limits of Optical Lithography	
13.9.2 Non-Optical Microlithographic Technologies	
13.9.2.1 Electron Beam Direct-Write Lithography	
13.9.2.2 Electron Beam Projection Lithography (SCALPEL)	
13.9.2.3 Extreme Ultra-Violet Reflective Projection Lithography (EUV)	
13.9.2.4 Proximity X-Ray Lithography	
13.9.2.5 Ion-Beam Projection Lithography	
REFERENCES,	650
PROBLEMS,	654
14. DRY ETCHING FOR VLSI	855
14.1 THE TERMINOLOGY OF ETCHING,	656
14.1.1 Bias, Tolerance, Etch Rate, and Anisotropy	
14.1.2 Selectivity, Over-Etch, and Feature Size Control	
14.1.3 Determining the Required Selectivity with Respect to Mask Materials, S_{fm}	
14.1.4 Determining Required Selectivity With Respect to Substrate, S_{fs}	
14.1.5 Combined Impact of the Requirements of Anisotropy and Selectivity	
14.1.6 Loading Effects and Microloading	
14.2 TYPES OF DRY-ETCHING PROCESSES,	666
14.3 BASIC PHYSICS AND CHEMISTRY OF PLASMA ETCHING,	667
14.3.1 The Reactive-Gas Glow Discharge	
14.3.2 Electrical Aspects of Glow Discharges	
14.3.3 Heterogeneous (Surface) Reaction Considerations	
14.3.4 Parameter Control in Plasma Processes	
14.4 ETCHING SILICON & SILICON DIOXIDE IN FLUOROCARBON PLASMAS,	673
14.4.1 The Fluorine-to-Carbon-Ratio Model	
14.5 ANISOTROPIC ETCHING AND CONTROL OF EDGE PROFILE,	678

Chapter 12

LITHOGRAPHY I:

OPTICAL PHOTORESIST MATERIALS

and PROCESS TECHNOLOGY

Microcircuit fabrication requires precisely controlled quantities of impurities to be introduced into tiny regions of the silicon substrate. Subsequently these regions must be interconnected to create components and VLSI circuits. The patterns that define such regions are created by lithographic processes. That is, a layer of photoresist materials is first spin-coated onto the wafer substrate. Next, this resist is selectively exposed to a form of radiation, such as ultraviolet light, electrons, or x-rays. An exposure tool and mask are used to effect the desired selective exposure. The patterns in the resist are formed when the wafer undergoes a subsequent "development" step. The areas of resist remaining after development protect the substrate regions which they cover. Locations from which resist has been removed can be subjected to a variety subtractive (e.g., etching) or additive (e.g., ion implantation) processes that transfer the pattern onto the substrate surface. An advanced IC can have 20 or more masking layers. Approximately one-third of the total cost of semiconductor manufacturing can be attributed to microlithographic processing.

Two chapters of this text are devoted to the details of lithographic processing for ULSI. The first is concerned with the properties of photoresist materials and the resist processing technology utilized in ULSI fabrication. The discussion is restricted to resists exposed by optical (e.g., UV and DUV) radiation. The second chapter deals with the tools used to expose the resist. That is, optical aligning equipment and photomasks are described, as well as alternatives to optical lithography, including electron beam and x-ray patterning technology.

In general, users of resists are not overly concerned with the complexities of resist chemistry, but rather how well the resist will function in their process. The majority of the information in this chapter is presented with this focus. Photoresists have been used in the printing industry to make pre-coated lithographic printing plates for more than a century. In the 1920s photoresists found wide application in the printed circuit board industry. The semiconductor industry adapted this technique for wafer fabrication in the 1950s. By 1991 the semiconductor industry consumed about 2500 tons of photoresist per year, which represented a sales of around \$220 million (\$US). The selling price of photoresist in the late 1990's was about \$900/gallon. In the early days of the IC industry there were a large number of resist suppliers. As the lithography process matured, the number of vendors consolidated, and by the end of the century a much smaller number remained. In the U.S. there are two resist vendors, Olin Microelectronic Materials (who purchased McDermitt, Ciba-Geigy and KTI (Kodak)), and the Shipley Company. Foreign suppliers include Clariant Corp. (formerly AZ Electronic Materials), Tokyo Ohka Kogyo, and JSR Microelectronics.

Chapter 13

LITHOGRAPHY II:

OPTICAL ALIGNERS and

PHOTOMASKS

In the previous chapter the material properties of photoresists and their processing technology were covered. This chapter will describe the remainder of the topics involved in the microlithographic process of transferring patterns to silicon wafers, including: a) a brief introduction to the optical science involving the formation of aerial images of the circuit patterns on the resist surface; b) the equipment used to project these images onto the wafer surface (the so-called *aligners* or *printers*); c) the pattern transfer tools that contain the patterns to be printed onto the photoresist-coated wafers (the photomasks and reticles); and 4) non-optical microlithographic technologies that are being investigated as replacements for optical lithography.

Before beginning the discussion on optics, however, it is useful to identify the key issues of microlithography hardware. The most important characteristics of the machines and masks used to project the patterns onto wafer surfaces are the following: a) resolution; b) pattern registration capability (alignment and overlay); c) dimensional control; and d) throughput.

In general, the term *resolution* of an *optical system* describes its ability to print a minimum feature size. Specifically, the *minimum resolution* of a microlithographic printing machine will be referred to as the dimension of minimum linewidth or space that the machine can adequately print (or *resolve*). The ability to form IC features of such minimum dimensions also depends on the photoresist and the etching technology. The topic of resolution of optical systems is dealt with more thoroughly in the section on *Optics of Microlithography*, but it is important to emphasize that *high resolution* is usually the most sought after property of an aligner. The subject of resolution of optical lithography systems will be briefly discussed here, admittedly using some terms that are not defined until later.

Consider the case of an isolated transparent line on an opaque mask. The intensity of the light projected onto the wafer surface (as a function of the normalized distance from the center of the line) is shown in Fig. 13-1 for: 1) the ideal case; and 2) the actual case for three different line widths (i.e., 0.35 μm , 0.25 μm , and 0.18 μm) when imaged by a specific optical system containing a perfect (distortion-free) lens. In this example, the NA of the lens is 0.5, the illuminating wavelength is 0.248 μm , and the system has a partial coherence of $\sigma = 0.6$. Even though all of these terms have not yet been defined, what is important to note is that for any specific optical system, as the dimension of the line gets smaller, there is a degradation of the